WAVELET AND VECTOR QUANTIZATION IMAGE COMPRESSION FOR NOISY CHANNEL TRANSMISSION

FINAL PROGRESS REPORT

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13. ABSTRACT *(Maximum 200 words)*
In the research conducted under this grant, we addressed the problem of transmitting images compressed with high quality wavelet compression algorithms over packet erasure networks, multiple description channels, and noisy communication channels. In addition, we developed new methods for wavelet image compression based on group testing; developed a variation of the set partitioning in hierarchical trees algorithm; and developed a method for fast search of an entropy-constrained vector quantization codebook.

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1 Statement of the Problem Studied

In the research conducted under this grant, we addressed the problem of transmitting images compressed with high quality wavelet compression algorithms over packet erasure networks, multiple description channels, and noisy communication channels. In addition, we developed new methods for wavelet image compression based on group testing; developed a variation of the set partitioning in hierarchical trees (SPIHT) [16] algorithm; and developed a method for fast search of an entropy-constrained vector quantization codebook.

2 Summary of Most Important Results

In this Section, we summarize our most important results.

2.1 Graceful Degradation of Compressed Images Over Packet Erasure Channels

Under the grant's support, we developed an unequal loss protection (ULP) algorithm to assign unequal amounts of forward error correction (FEC) to images that are compressed with an unmodified progressive compression algorithm, such as SPIHT, and transmitted over lossy packet networks [11, 12]. Our scheme is modular in that we can use any progressive compression algorithm and have graceful degradation with increasing packet loss rate. That is, if more packet loss occurs on a network, the receiver will decode a lower rate version of the image. If the network is congested when someone tries to download an image, instead of the connection stalling while waiting for retransmissions, a slightly degraded view of the image could be displayed.

In generalized multiple description coding, N packets of data are transmitted and possibly less than N packets are received. The goal is to maximize the quality of the reconstruction given the received packets. This is equivalent to coding for lossy packet networks.

We have developed a way to use our ULP algorithm to implement a SPIHT-based multiple description image coder [9, 10]. FEC is assigned across packets in unequal amounts so that if packet or description loss occurs, useful data can still be received. Initial simulations were very promising and gave results that were higher than recent results by Chung and Wang [2] by up to 2.87 dB.

Current extensions of this work include applying the ULP algorithm to video compression and developing a real-time ULP algorithm. We have recently received a grant to implement our ULP algorithm in the high quality wavelet-based image coder of LizardTech, Inc. (www.lizardtech.com). The goal is that even if severe amounts of packet loss occur on the Internet, a useful image could be obtained from any image server that is using the LizardTech encoder.

2.2 Multiple Description SPIHT

We have developed an alternative method for protecting data in a multiple description coder or lossy packet network. The algorithm is designed for SPIHT but can be extended to other coding methods. It divides the data into descriptions and adds redundancy before compression.

In this method, to improve the robustness of SPIHT to packet loss, we first modify it similarly to the Packetized Zerotree Wavelet algorithm of Rogers and Cosman [15]. We deinterleave the SPIHT bit stream by combining spatially disperse wavelet coefficient trees and coding them with SPIHT in separate descriptions. We use arithmetic coding within each description and code each description to the same bit rate.

Redundancy is added by placing extra copies of each wavelet coefficient tree in additional descriptions. To vary the amount of redundancy according to the importance of data, we code each copy of a tree at successively lower bit rates. Each description has fully coded original trees and some partially coded redundant trees corresponding to different spatial locations in the image. Results show that high quality images can be obtained even when up to half of the descriptions are lost.

Future work includes frame expansions [6, 5] in the MD-SPIHT coder. In addition, we are extending our algorithm to protect a region of interest in an image more heavily than the rest of the image [8].

2.3 Group Testing for Image Compression

We developed a novel wavelet-based compression algorithm based on the concept of group testing. We call this algorithm Group Testing for Wavelets (GTW). Group testing is a technique for identifying a few significant items out of a large pool of items. Whereas Shapiro's embedded zerotree wavelet (EZW) coder [17] and SPIHT rely on zerotrees to code wavelet coefficients, GTW codes wavelet coefficients in groups that do not have to be zerotrees. Therefore, GTW is a generalization of the EZW and SPIHT algorithms and should be able to offer better coding performance.

Our results showed that even though the GTW algorithm does not use arithmetic coding, it performs comparably to the SPIHT variant with arithmetic coding. It outperforms SPIHT without arithmetic coding on the Barbara image by up to 0.7 dB.

In our future work, we will extend GTW to image transforms that are of lower complexity than the wavelet transform, such as the discrete cosine transform, and to the compression of wavelet packet coefficients [3, 14, 4]. We believe that GTW will be particularly well suited for coding wavelet packets since wavelet packet coefficients are more difficult to group into standard SPIHT-like zerotrees.

2.4 EZV

At StatSci, the subcontractor on the grant, we carried out a rate-distortion analysis of Shapiro's EZW coding algorithm. We also developed a variation of embedded zerotree coding that we call EZV coding. It uses a 1-bit alphabet and 1-depth lookahead coding in the EZW algorithm. EZV codes the same information as the EZW, but more efficiently, resulting in significant bit savings for the same information. Code for this work has been implemented in StatSci's Splus Wavelets 2.0 module.

2.5 Fast Search of Entropy-Constrained Vector Quantization

Entropy-constrained vector quantization (ECVQ) [1] offers substantially improved image quality over ordinary vector quantization (VQ). It uses a Lagrangian distortion measure that trades off the distortion between an input vector and a candidate codeword, and the cost in bits of sending the codeword (its entropy). Larger VQ codebooks offer higher image quality for a given bit rate. The drawback of using an extremely large codebook is that it requires high complexity at the encoder.

There has been a substantial amount of work in the literature for fast search of ordinary VQ, which uses the mean-squared error as its distortion measure. We developed a new technique for fast search of ECVQ [7] so that larger codebooks can be used in ECVQ with manageable complexity. We use a new, easily computed distance that successfully eliminates most codewords from consideration. Speedup over exhaustive search of a size 512 codebook of 4×4 vectors is almost 20:1. It can be used with any variant of VQ that uses a Lagrangian distortion measure, such as Bayes-risk VQ.

2.6 An Empirical Study of Fast VQ Search Algorithms

In related work, we compared six nearest neighbor search algorithms for performing VQ. Orchard's Method [13], the Annulus Method, and the Double Annulus Method are algorithms designed specifically for VQ. The *k-d* tree nearest neighbor search algorithm is a traditional, general-purpose algorithm. The last two algorithms, called the PCP tree and the PCP/*k-d* tree, were newly developed by the authors.

These six algorithms are compared empirically. The results of this study are the following.

- All six algorithms are vastly superior to "brute–force" search.
- In low dimension (4 or less), the *k-d* tree is the fastest.
- In high dimension with small codebooks, Orchard's Method is fastest. However, the memory requirements of Orchard's Method make it impractical for all but the smallest searches.
- The PCP/*k-d* tree is a competitive alternative to Orchard's Method, and is the best general–purpose algorithm.

2.7 Recovering from Bit Errors in Images Compressed with Wavelets and Scalar Quantization

We studied the effects of transmission noise on fixed-length coded wavelet coefficients. We developed a maximum a posteriori detector that uses inter-bitplane information to determine which transmitted codeword was most likely transmitted for a given received erroneous codeword. We presented a simple method of recovering from these errors once detected and applied our restoration methodology to scalar-quantized wavelet coefficients that were transmitted across a binary symmetric channel. Results show that our method can increase the peak signal-to-noise ratio by nearly 4 dB for the Lenna image transmitted over a binary symmetric channel with an error rate of 1%.

3 List of All Publications and Technical Reports That Acknowledge This Grant

1. Journal Papers

   (a) Jill R. Goldschneider and Eve A. Riskin, "Optimal Bit Allocation and Best-Basis Selection for Wavelets and TSVQ." IEEE Transactions on Image Processing, 8(9): 1305-1309, September 1999.

   (b) Alexander E. Mohr, Eve A. Riskin, and Richard Ladner, "Generalized Multiple Description Coding through Unequal Loss Protection." Submitted to the IEEE Transactions on Circuits and Systems for Video Technology for possible publication, October 1999.

   (c) Alexander E. Mohr, Eve A. Riskin, and Richard E. Ladner, "Unequal Loss Protection: Graceful Degradation of Image Quality Over Packet Erasure Channels through Forward Error Correction." To appear in the IEEE Journal of Selected Areas in Communications Special Issue on Error-Resilient Image and Video Transmission, 2000.

   (d) Mary Holland Johnson, Richard E. Ladner, and Eve A. Riskin, "Fast Nearest Neighbor Search for ECVQ and Other Lagrangian Distortion Measures." To appear in the IEEE Transactions on Image Processing.

2. Conference Papers

   (a) Alexander E. Mohr, Eve A. Riskin, and Richard Ladner, "Bit Allocation for Wavelet Image Compression and Uniform Bit Loss." pp. 981-982, *Proceedings of the 32th Annual Conference on Information Sciences and Systems*, March 1998.

   (b) Alexander E. Mohr, Eve A. Riskin, and Richard Ladner, "Recovering from Bit Errors in Scalar-Quantized Discrete Wavelet Transformed Images." *Proceedings of ICIP 1998*, Volume III, pp. 502-506, October 1998.

   (c) Kevin Zatloukal, Mary Holland Johnson, and Richard Ladner "Algorithm Engineering and Experimentation: ALENEX '99 Workshop" January 1999.

(d) Alexander E. Mohr, Eve A. Riskin, and Richard Ladner, "Graceful Degradation Over Packet Erasure Channels Through Forward Error Correction." Proceedings Data Compression Conference, pp. 92-101, March 1999.

(e) Agnieszka C. Miguel, Alexander E. Mohr, and Eve A. Riskin, "SPIHT for Generalized Multiple Description Coding." Proceedings of ICIP 1999.

(f) Alexander E. Mohr, Richard E. Ladner, and Eve A. Riskin, "Generalized Multiple Description Coding through Unequal Error Correction." Proceedings of ICIP 1999.

(g) Edwin Hong and Richard E. Ladner, "Group Testing for Image Compression." To appear in the Proceedings of the 2000 Data Compression Conference.

(h) Agnieszka C. Miguel and Eve A. Riskin, Protection of Regions of Interest Against Data Loss in a Generalized Multiple Description Framework." To appear at the 2000 Data Compression Conference (abstract only).

4 List of All Participating Scientific Personnel Showing Advanced Degrees

Under this grant's tenure, five Ph.D. students were supported. Two of them completed the Ph.D. degree, one received a Master's degree, and the other two passed their General examination. The students are:

- Dr. Jill Goldschneider, Ph.D. in Electrical Engineering, May 1997. Thesis topic: "Lossy Compression of Scientific Data." She is employed at the Data Analysis Products Division of MathSoft, Seattle, WA.

- Mary Holland Johnson, "Data Compression for Low Bit Rate Transmission of Marine Imagery." Ph.D in EE, June, 1999. Is employed at the Naval Undersea Warfare Command, Newport, RI.

- Mr. Alexander E. Mohr, MS in Bioengineering, March 1999. He is currently a Ph.D. student in the University of Washington Computer Science and Engineering department.

- Ms. Agnieszka Miguel advanced to Ph.D. candidacy in May 1999. She expects to complete her Ph.D. in Electrical Engineering in early 2001.

- Mr. Edwin Hong advanced to Ph.D. candidacy in December 1999. He expects to complete his Ph.D. in Computer Science and Engineering in late 2001.

5 Inventions

- "Unequal Erasure Protection Algorithm for Assigning Forward Error Protection to Progressive Compressed Data," filed with the University of Washington Office of Technology Transfer.

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